Request for More Data in the Horn-off Configuration

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The potential ν_e oscillation signal in the MINOS Far Detector has 4 principal background contributions: NC events misidentified as ν_e, CC events misidentfied as ν_e, beam ν_e events and ν_τ events. The first 3 sources can be measured or estimated in the Near Detector. The extrapolation to the Far Detector is more complex than for the case of the CC disappearance analysis because different background sources extrapolate differently. Thus some knowledge about the relative contribution from the three sources is necessary. The studies so far focused on obtaining relative CC and NC contributions from comparison of background rates in the horn-on and horn-off configurations. These two configurations give significantly different ratios of CC to NC backgrounds and thus a comparison of background levels can yield information regarding relative contributions from these two sources.

This background estimate technique using horn-off data was described in MINOS-doc-1502. The latest results were presented in MINOS-doc-3301 and MINOS-doc-3325. The error on the NC background estimate can be written as:

$$\begin{aligned}\delta NC^2 = &(\frac{r_{CC}}{r_{NC}-r_{CC}})^2\delta N_{on}^2 + (\frac{1}{r_{NC}-r_{CC}})^2\delta N_{off}^2 + (\frac{r_e-r_{CC}}{r_{NC}-r_{CC}})^2\delta N_e^2 \\ &+(\frac{NC}{r_{NC}-r_{CC}})^2\delta r_{NC}^2 + (\frac{CC}{r_{NC}-r_{CC}})^2\delta r_{CC}^2 + (\frac{\nu_e}{r_{NC}-r_{CC}})^2\delta r_e^2 \end{aligned} \quad (1)$$

$N_{on(off)}$ is the number of observed events in the horn-on(off) configuration that pass the ν_e cut. CC, NC and N_e are the numbers of CC, NC and beam ν_e events respectively. r_{CC}, r_{NC} and r_e are the ratios of the contribution from different channels to the background in the horn-off vs horn-on configurations. N_e and the 3 ratios have to be estimated from Monte Carlo, we assign a 10% error to N_e, a 5% error to r_{NC}, a 20% error to r_{CC} and a 15% error to r_e (MINOS-doc-3325):

$$N_e = 1140 \pm 114, r_{CC} = 0.131 \pm 0.026, r_{NC} = 0.498 \pm 0.025, r_e = 0.189 \pm 0.026$$

If we take a sample of 1E19POT horn-on data and all the **2.8e18**POT of horn-off data and normalize the numbers to 1E19POT, we have:

$$N_{on} = 11318 \pm 105, N_{off} = 4157 \pm 122$$

The numbers of NC and CC events that pass the ν_e cut can be calculated (MINOS-doc-3301):

$$NC = 7095, CC = 3084$$

The Systematic error on the NC background estimate is therefore:

$$\delta NC = \sqrt{37.7^2 + 331.1^2 + 17.9^2 + 481.9^2 + 221.0^2 + 82.3^2}^{1} = 631.8$$

The contribution from the statistics of the data in the horn-off configuration is 331.1, which is the second largest contribution. The first term is small and will be highly reduced when we use all the available ND data in the horn-on configuration. The contribution from the uncerntainty on the beam ν_e events is also small (17.9). The uncerntainty on the ratio, r_{NC}, has the biggest contribution(481.9), but this might also be reduced in the future when we have a better understanding of the Monte Carlo. Increasing the Monte Carlo statistics will also help to reduce the error on r_{NC} and we have already requested more horn-off MC.

If we can double our data in the horn-off configuration and reduce the errors on the 3 ratios by a factor of 2 which seems to be achievable based on preliminary studies, the systematic error on NC background will be:

$$\delta NC = \sqrt{37.7^2 + 0.5 \times 331.1^2 + 17.9^2 + 241.0^2 + 111.0^2 + 41.2^2} = 358.7$$

which is much lower than the current estimate.

If we can get an extra **6e18POT** of horn-off running, which will triple our data in the horn-off configuration, and reduce the errors on the 3 ratios by a factor of 2, the systematic error on NC background will be:

$$\delta NC = \sqrt{37.7^2 + (1/3) \times 331.1^2 + 17.9^2 + 241.0^2 + 111.0^2 + 41.2^2} = 332.2$$

Based on the above calculations, we would like to request between **3e18POT** and **6e18POT** of additional data running in the horn-off configuration which corresponds to roughly one to two weeks of running. This will help to reduce the systematic error in the ν_e analysis. The data beyond 3e18POT will be helpful when doing this same analysis as function of energy.

[1]The position of the evaluated terms corresponds to the position of the terms given in Equation (1)